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I also certify that the attached copy of the request for grant of a Patent (Form 1/77) bears an amendment, effected by this office, following a request by the applicant and agreed to by the Comptroller-General.

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Request for grant of a patent

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)

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19NOV03 E853279-1 C93846
P01/7700 0.00-0326894.3

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1. Your reference

VAPOUR ENTRAINMENT

2. Patent application number
(The Patent Office will fill this part in)

0326894.3

19 NOV 2003

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

MR DONALD STUART MILLER
BROOKSIDE
CHURCH WALK
HARROLD
BEDFORD
MK43 7DG

Patents ADP number *(if you know it)*

8553901001

If the applicant is a corporate body, give the country/state of its incorporation

4. Title of the invention

ABRASIVE IN VAPOUR ENTRAINMENT

5. Name of your agent *(if you have one)*

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

TM Gregory & Co
26 Cyril Street
Northampton
NN1 5EL
(F51/77 13.1.05)

Patents ADP number *(if you know it)*

6. Priority: Complete this section if you are declaring priority from one or more earlier patent applications, filed in the last 12 months.

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. Divisionals, etc: Complete this section only if this application is a divisional application or resulted from an entitlement dispute (see note f)

Number of earlier UK application	Date of filing *(day / month / year)*

8. Is a Patents Form 7/77 (Statement of inventorship and of right to grant of a patent) required in support of this request?

NO

Answer YES if:
a) any applicant named in part 3 is not an inventor, or
b) there is an inventor who is not named as an applicant, or
c) any named applicant is a corporate body.
Otherwise answer NO (See note d)

9. Accompanying documents: A patent application must include a description of the invention. Not counting duplicates, please enter the number of pages of each item accompanying this form:

Continuation sheets of this form	
Description	4
Claim(s)	
Abstract	
Drawing(s)	1 +1

CL

10. If you are also filing any of the following, state how many against each item.

Priority documents	
Translations of priority documents	
Statement of inventorship and right to grant of a patent (Patents Form 7/77)	
Request for a preliminary examination and search (Patents Form 9/77)	
Request for a substantive examination (Patents Form 10/77)	
Any other documents (please specify)	

11. I/We request the grant of a patent on the basis of this application.

Signature(s) Date 18 Nov 03

12. Name, daytime telephone number and e-mail address, if any, of person to contact in the United Kingdom DON MILLER 01234 721089

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d) If you have answered YES in part 8, a Patents Form 7/77 will need to be filed.

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Abrasive in Vapour Entrainment

The present invention relates to the entrainment of abrasive particle/vapour mixtures into high velocity liquid jets and the condensation of the vapour to produce abrasive/liquid cutting jets. Normally, but not exclusively, the liquid is water, the vapour is steam and the abrasive a powder such as garnet or aluminium oxide.

More effective abrasive waterjet systems are needed to meet market demands for faster cutting and greater cut surface area generation per kilogram of abrasive. Only one method of generating abrasive waterjets is in widespread use for precision machining and after 20 years of refinements it is unlikely that this method can be improved dramatically to match the level of performance gains of competing technologies such as lasers. There is therefore a need for new methods of generating abrasive waterjets and in particular methods that generate smaller jet diameters, for a given power input, to reduce the amount of work piece material removed in making cuts.

Abrasive in air entrainment is the established method of generating abrasive waterjets for precision machining. Water at ultra high pressures of 2500 to 4000bar is passed through a sharp edged orifice to generate a jet moving at over 700m/s. The water jet traverses a chamber to entrain air that conveys abrasive particles into the chamber. The waterjet along with the air and abrasive leave the chamber via a ceramic mixing tube that is aligned along the axis of the waterjet orifice. In the mixing tube momentum is transferred from the water to the initially slow moving abrasive particles. Abrasive/water/air mixtures leave mixing tubes as focused cutting jets and impact on work pieces with cutting spot diameters that are slightly larger than mixing tube bore diameters.

Air has a density about 1000 times less than water and readily accelerated by water jets to enter mixing tubes at sonic velocity. However, the volume of air needed to convey and drag abrasive particles into mixing tubes is such that mixing tube bore cross sectional areas have to be some 9 to 16 times the area of the water jet vena contracta. This means that abrasive in air cutting heads produce cutting spot diameters and hence cut widths that are 3 to 4 times that of waterjet vena contracta diameters.

Passing a pressurised suspension of abrasive in water through a nozzle produces the maximum cutting spot energy density and can provide a factor of 5 increase in cutting performance, relative to abrasive in air entrainment. However, handling suspensions at ultra high pressures is very difficult and not commercially practical so improved cutting heads must operate by entrainment processes. This patent application concerns replacing air as the abrasive conveying fluid to improve momentum transfer efficiencies in mixing tubes and allow smaller mixing tube bore diameters.

UK Patent Application No. 0227412.4 describes cutting heads that entrain high-density abrasive mixtures with 25%wt or so water. The cutting heads described can operate with cutting spot diameters less than 1.4 times waterjet vena contracta diameters. The water in abrasive mixtures has to be accelerated in the cutting heads described and additives are necessary for the functioning of abrasive mixture feed systems and the entrainment process.

For a range of applications it is desirable not to have to prepare abrasive in water mixtures, to accelerate additional water and/or to use additives.

The method of generating abrasive waterjets described in this application involves conveying abrasive particles to cutting heads using a vapour that condenses in the cutting head. By condensing the vapour mixing tube bore diameters can be greatly reduced, compared to those needed for abrasive in air entrainment. Steam condenses to less than one thousandth of its volume at near atmospheric pressures. The condensed water amounts to under 1%wt of the mass flow, so other effects being equal, the effectiveness of abrasive in steam entrainment is higher than abrasive in water entrainment and much higher than abrasive in air entrainment.

Steam condensation is a powerful mechanism for generating flows to carry abrasive particles to cutting heads. Small diameter waterjets that could not entrain sufficient air to convey abrasive can condense sufficient steam to convey abrasive. Cutting heads that utilise abrasive in steam entrainment can operate with cutting spot diameters below 200μm, compared to over 300μm for abrasive in air entrainment.

The flow and momentum transfer mechanisms in mixing tubes are very different between abrasive in air and abrasive in steam entrainment. In abrasive in air entrainment momentum transfer takes place in a droplet/particle/air environment with an effective density of water divided by the square of the mixing tube bore to waterjet diameter ratio. The low effective density in mixing tubes requires tube lengths of 50 or so bore diameters to reach 90% of the maximum abrasive particle velocity. The low effective density does however mean that wall frictional effects are low and this allows the length of mixing tubes to be increased to collimate the flow without incurring excessive further energy losses. In the case of abrasive in steam entrainment the effective density is that of water and abrasive particles are accelerated to 90% or so of the maximum velocity in a distance less than 10 mixing tube diameters. Frictional losses are high in abrasive in steam mixing tubes, making it important to minimise mixing tube lengths needed to collimate the flow and this needs good initial particle distribution around and into waterjets.

Mixing tubes for abrasive in air entrainment are manufactured from tungsten carbide and only have lives of 1 to 100 hours, depending on the grade of tungsten carbide and abrasive hardness. Because much shorter mixing tubes are required for the cutting heads described in this patent application mixing tubes can be economically manufactured from diamond materials which are much more wear resistance than any grade of tungsten carbide.

According to the first aspect of the present invention there is provided a method of entrainment of abrasive particles into high velocity liquid jets to give abrasive cutting jets, the method comprises the step of providing pressurised liquid to a restriction to form a high velocity liquid jet, a metered supply of abrasive particles, a source of carrier vapour that is condensed by the liquid jet and conduit means through which vapour flow carries said abrasive particles to be entrained into the said liquid jet

The liquid is preferably water

The vapour is preferably dry steam

The abrasive is preferably garnet, olivine or aluminium oxide

The abrasive is preferably heated to above the condensation temperature of the steam

According to a second aspect of the present invention, there is provided apparatus to generate an abrasive cutting jet, the apparatus comprising a pressurised water supply and a nozzle to form a waterjet, an abrasive particle entry chamber and a mixing tube in which a suspension of abrasive particles in steam is entrained and the steam condenses and momentum is exchanged between the high velocity waterjet and abrasive particles.

Preferably the mixing tube comprises diamond.

The waterjet nozzle may form part of the load bearing structure of a cutting head.

Preferably the ratio of mixing tube to waterjet orifice diameters are between 1.2 to 1.5

The mixing tube may comprise a transition zone of diameter progressively decreasing from an abrasive entry chamber to a near parallel bore.

Mixing tubes may consist of two or more sections with transitions between sections to smaller bores in second and subsequent sections.

The abrasive mixture entry chamber may be lined or constructed from low thermal conductivity material.

According to a third aspect of the present invention, there is provided a means of generating and feeding steam to the said apparatus.

Preferably the steam is generated using electric heating.

Preferably the electric heating is by positive temperature coefficient heaters

According to a forth aspect of the present invention, there is provided a means of metering abrasive to the said apparatus.

According to the fifth aspect of the present invention, there is provided a means of directing the abrasive/water flow from said mixing tube of said apparatus onto work pieces.

The design of abrasive in steam cutting heads and their abrasive feed systems are described with reference to:

Figure 1 shows an abrasive in steam cutting head
Figure 2 shows a flow circuit for feeding abrasive to abrasive in steam cutting heads

Referring to Figure 1, pressurised water enters a cutting head 7 through conduit 1. The water passes through nozzle 6 to form a jet that traverses mixing chamber 8 and into the mixing tube 4. Steam carrying abrasive enters the cutting head 7 through conduit 2 to chamber 8, which connects to a transition region 5 to the bore 9 of mixing tube 4. Entrainment and axial acceleration of the abrasive particles and condensation of steam takes place in chamber 8 and transition 5 with the most of the momentum exchange between water and abrasive occurring in the mixing tube bore 9. Abrasive/water mixture leaves the bore 9 of mixing tube 4 as a cutting jet 3. Typically the ratios of diameters of mixing tube 9 to nozzle 6 are 1.2 to 1.5.

The mixing tube 4 will usually be manufactured from solid polycrystalline diamond or other form of diamond.

Connection 2 and chamber 8 may be lined with or constructed from low thermal conductivity, abrasive resistance materials.

It is desirable for the outlet from nozzle 6 to be within a few jet diameters of the inlet to the transition region 5 of mixing tube 4 and this may require nozzle 6 to form part of the structure resisting fluid pressure loads. These loads may exceed 400N per square millimetre. A shaped bore for nozzle 6 is preferably machined in a diamond blank that forms part of the pressure retaining structure of cutting head 7.

Figure 2 shows a flow circuit for feeding abrasive to cutting heads such as shown in Figure 1. Abrasive particles from vessel 21 flow via conduit 22, metering device 23 and conduit 24 to junction 25 where the particles are mixed with steam flow from steam generator 27 flowing along conduit 26 to junction 25. From junction 25 the abrasive is carried through conduit 2 by steam flow and into cutting head 7. Abrasive in vessel 21 may be heated to prevent condensation on the particles whilst flowing to cutting head 7 and the abrasive particles in vessel 21 may be blanked in steam to prevent air reaching the cutting head 7.

Provision may be made for trace heating of all components and conduits in the feed circuit of Figure 2 and for pre warming of the circuit and flow surfaces in cutting head 7 before abrasive flow is commenced to cutting head 7.

Junction 25 may take the form of an educator with an inlet nozzle size that enables pressures in the steam generator 27 and passage 26 to be maintained above atmospheric pressure and/or provide the driving mechanism to induce abrasive flow through metering device 23. The driving steam may pass down through the abrasive feed vessel to assist in metering abrasive out of the vessel.

Steam generator 27 is preferably electric powered. A power input of less than 1kW is sufficient to provide steam for abrasive flows up to 0.5kg per minute but higher power inputs may be used particularly for warming up the flow circuit prior to starting abrasive flow. The steam may be superheated in the steam generator or after the generator.

Positive temperature coefficient heaters may be used to limit temperatures and pressures. Typical steam conditions are 3 bar at the steam generator and 150 C temperature, allowing engineering plastics to be used for tubes and components.

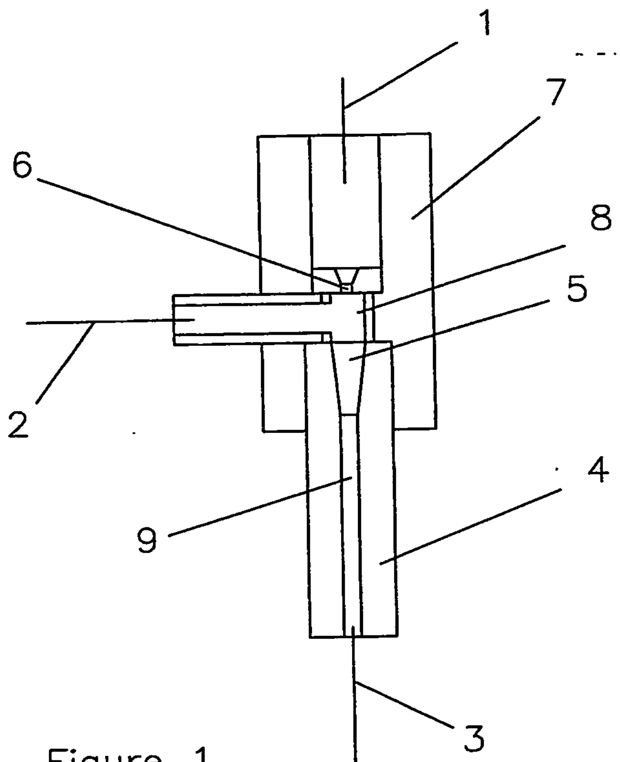

Figure 1

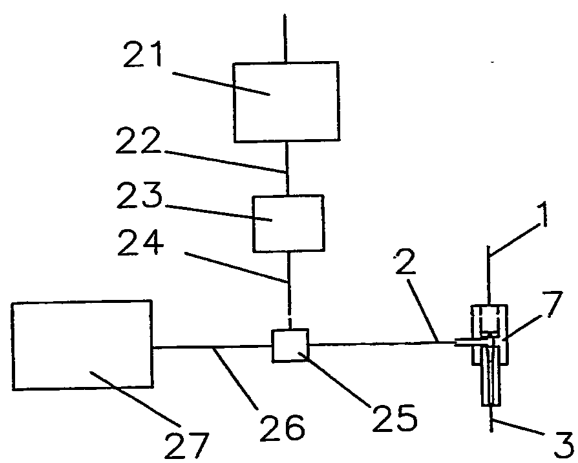

Figure 2

Document made available under the Patent Cooperation Treaty (PCT)

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International filing date: 15 November 2004 (15.11.2004)

Document type: Certified copy of priority document

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